

CLAIMS

1. A multi-layer piezoelectric element comprising a stack formed by stacking piezoelectric layers and internal electrodes alternately one on another and external electrodes formed on a first side face and on a second side face of the stack, one of the adjacent internal electrodes being connected to the external electrode formed on the first side face and the other internal electrode being connected to the external electrode formed on the second side face,
wherein the external electrodes include an electrically conductive material and glass, the external electrodes being formed from a porous electrically conductive material that has a three-dimensional mesh structure.
2. The multi-layer piezoelectric element according to claim 1;
wherein the external electrodes are partially joined onto the first side face and the second side face.
3. The multi-layer piezoelectric element according to claims 1 or 2;
wherein an electrically conductive material of the external electrodes includes silver as the main component.
4. The multi-layer piezoelectric element as in one of claims 1-3;
wherein the softening point of the glass used in the external electrodes is not higher than the melting point of the electrically conductive material that constitutes the external electrodes.
5. The multi-layer piezoelectric element as in one of claims 1-4;
wherein the metal component of the internal electrode includes Ag as the main component and 15% by weight or less of at least one kind of the Pd and Pt group metals.
6. A multi-layer piezoelectric element comprising a stack formed by

stacking piezoelectric layers and internal electrodes alternately one on another and external electrodes formed on a first side face and on a second side face of the stack, one of the adjacent internal electrodes being connected to the external electrode formed on the first side face and the other internal electrode being connected to the external electrode formed on the second side face,

wherein the internal electrodes and the external electrodes include silver, and

wherein the proportions of silver in the internal electrodes and in the external electrodes are set so that the ratio of silver content X (% by weight) to the entire electrically conductive material included in the internal electrode and the ratio of silver content Y (% by weight) to the total weight of the electrically conductive material and glass included in the external electrodes satisfy conditions of $X \geq 85$ and $0.9 \leq X/Y \leq 1.1$.

7. The multi-layer piezoelectric element according to claim 6;

wherein the internal electrode contains piezoelectric material, and

wherein the proportion Z (% by weight) of silver to the total weight of the internal electrode containing the piezoelectric material satisfies condition of $0.7 \leq Z/Y \leq 1.0$.

8. The multi-layer piezoelectric element according to claims 6 or 7;

wherein the external electrode is formed from a porous electrically conductive material that has 3-dimensional mesh structure.

9. The multi-layer piezoelectric element as in one of claims 6-8;

Wherein the softening point (°C) of the glass used in the external electrodes is not higher than 4/5 of the melting point (°C) of the electrically conductive material that constitutes the internal electrodes.

10. The multi-layer piezoelectric element as in one of claims 1-9;
wherein void ratio of the external electrode is in a range from 30 to 70% by volume.
11. The multi-layer piezoelectric element as in one of claims 1-10;
wherein a glass that constitutes the external electrode is amorphous.
12. A multi-layer piezoelectric element comprising a stack formed by stacking piezoelectric layers and internal electrodes alternately one on another and external electrodes formed on a first side face and on a second side face of the stack, one of the adjacent internal electrodes being connected to the external electrode formed on the first side face and the other internal electrode being connected to the external electrode formed on the second side face, the internal electrodes being made of an electrically conductive material that contains silver as the main component and at least one of palladium and platinum, the external electrodes being made of a conductive material including silver as a main component and glass,
wherein the proportion of silver contained in electrically conductive material of the internal electrode near the junction with the external electrode is higher than the proportion of silver contained in electrically conductive material of the internal electrode located inside of the stack.
13. The multi-layer piezoelectric element according to claim 12;
wherein the proportion of silver contained in electrically conductive material of the internal electrode becomes higher toward the external electrode.
14. The multi-layer piezoelectric element according to claims 12 or 13;
wherein the proportion of silver contained in the electrically conductive material of the internal electrode is 85% by weight or higher.

15. The multi-layer piezoelectric element as in one of claims 12-14;
wherein the glass component contained in the external electrode exists in a region substantially not more than 80% in thickness of the external electrode on the side of the surface of the stack.
16. The multi-layer piezoelectric element as in one of claims 12-15;
wherein the glass component contained in the external electrode contains lead oxide or bismuth oxide.
17. The multi-layer piezoelectric element as in one of claims 12-15; wherein the external electrode and the internal electrode are joined by diffusion.
18. The multi-layer piezoelectric element as in one of claims 1-17;
wherein a glass-rich layer is formed on the surface of the external electrode on the side thereof facing the piezoelectric layer.
19. The multi-layer piezoelectric element as in one of claims 1-18;
wherein a thickness of the external electrode is smaller than a thickness of the piezoelectric layer that constitutes the stack.
20. The multi-layer piezoelectric element as in one of claims 1-19;
wherein a groove is formed between the end of the other internal electrode and the external electrode on the first side face, with the groove being filled with an insulating material and a groove is formed between the end of the one internal electrode and the external electrode on the second side face, with the groove being filled with an insulating material, the insulating material having Young's modulus lower than that of the piezoelectric material.
21. The multi-layer piezoelectric element as in one of claims 1-20; further comprising an electrically conductive assisting member formed from an electrically conductive adhesive, containing a metal mesh or a mesh-like metal

sheet embedded therein, on the external surface of the external electrode.

22. The multi-layer piezoelectric element according to claim 21;

wherein the electrically conductive adhesive is polyimide resin having electrically conductive particles dispersed therein.

23. The multi-layer piezoelectric element according to claim 22;

wherein the electrically conductive particles are silver particles.